Measurement of Heavy Flavor and Quarkonia Production by PHENIX

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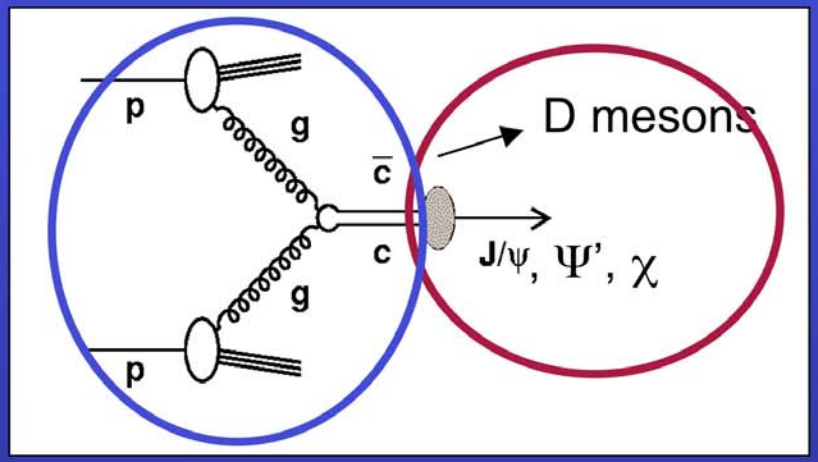
Talk Outline

- Physics of Heavy Flavor Production
- How Heavy Flavor can Probe the QGP
- Heavy Flavor Measurement Techniques
- PHENIX Detector Capabilities
- Current Measurement Results
- PHENIX/RHIC Upgrade Capabilities
- Summary

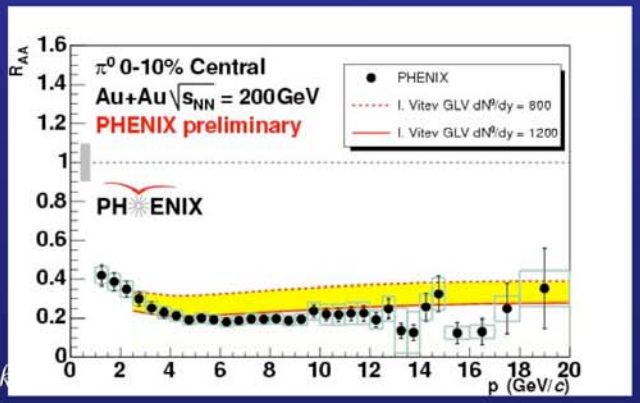
Heavy Flavor Production

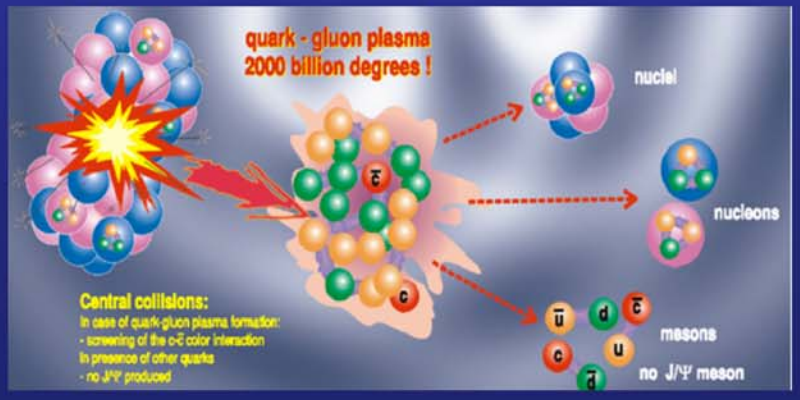


Factorize calculations:

- pQCD to calculate c-cbar production
- c-cbar propagation and Hadronization

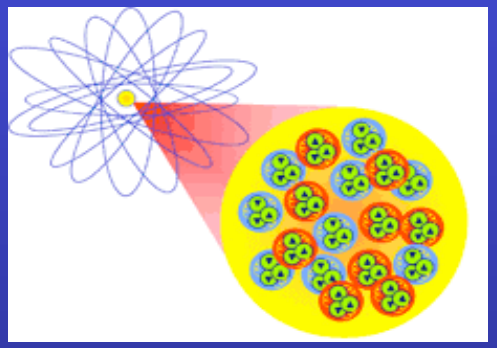
- Some heavy flavor production at RHIC dominated by gg interactions → gluon probe
- Generated in initial hard collisions → present from t_0 to probe of medium
- High mass → pQCD calculable, map out medium interactions vs. quark mass
- Medium Interactions (color screening, breakup & reformation)





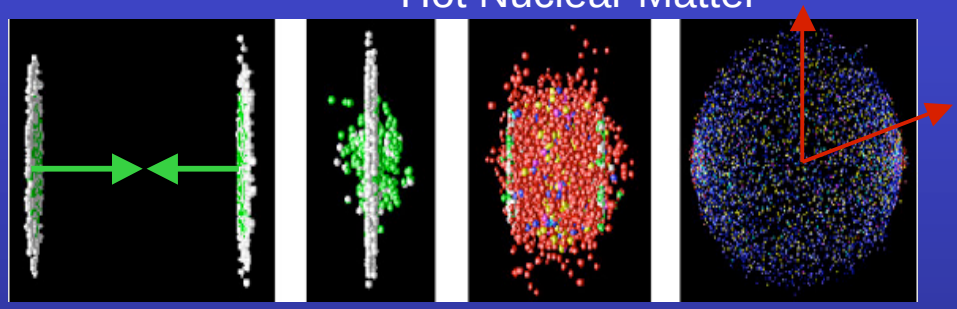
Heavy Flavor as a QGP Probe

Heavy flavor particles provide unique probe of QGP, but careful systematic study of production must be undertaken to pull out QGP-specific effects.



Cold Nuclear Matter

Hot Nuclear Matter



Extracting QGP properties from A+A collisions requires understanding of:

- Superposition of nucleon-nucleon collisions plus:
- PDF modification inside a nucleus?
- Does multiple scattering, energy loss of incoming partons traversing a nucleus significantly modify particle production? Absorption in nucleus?
- Extrapolation from d+A to A+A
- Finally, how does the QGP affect particle production:
  - Energy loss of the partons
  - Is formation altered because of medium: particles screened, or broken up and reformed?
  - What role does recombination play?

Extracting Physics

Heavy Flavor in p+p → baseline cross sections needed for AA, comparison to theory

R_{dAu} in d+Au → is production modified by cold nuclear matter

- Rapidity dependence → shadowing, energy loss
- p_T dependence → multiple scattering

R_{AA} in A+A → is production modified beyond cold nuclear matter effects in AA collisions?

- Rapidity, p_T, quark mass dependence can help determine whether model of cold nuclear matter and QGP effects can reproduce all spectra
- Similarly for flow
- Heavy flavor and quarkonia simultaneously modeled

Simultaneous modeling of all together likely needed to pull out any one component

Open Heavy Flavor Measurement Channels

- Hadronic decay modes allow full reconstruction of D mesons
- Preferred, but combinatorics issues, PID needed, statistically limited

D meson **Hadronic modes with one $\overline{K}$**

$K^-\pi^+$		(3.80 ± 0.07) %
$K^0_S\pi^0$		(1.14 ± 0.12) %
$K^0_S\pi^+\pi^-$	[qq]	(2.90 ± 0.19) %

- Semi-leptonic decays offer large branching ratios
- Challenging to remove background, D/B kinematics inferred, D/B separation often not possible

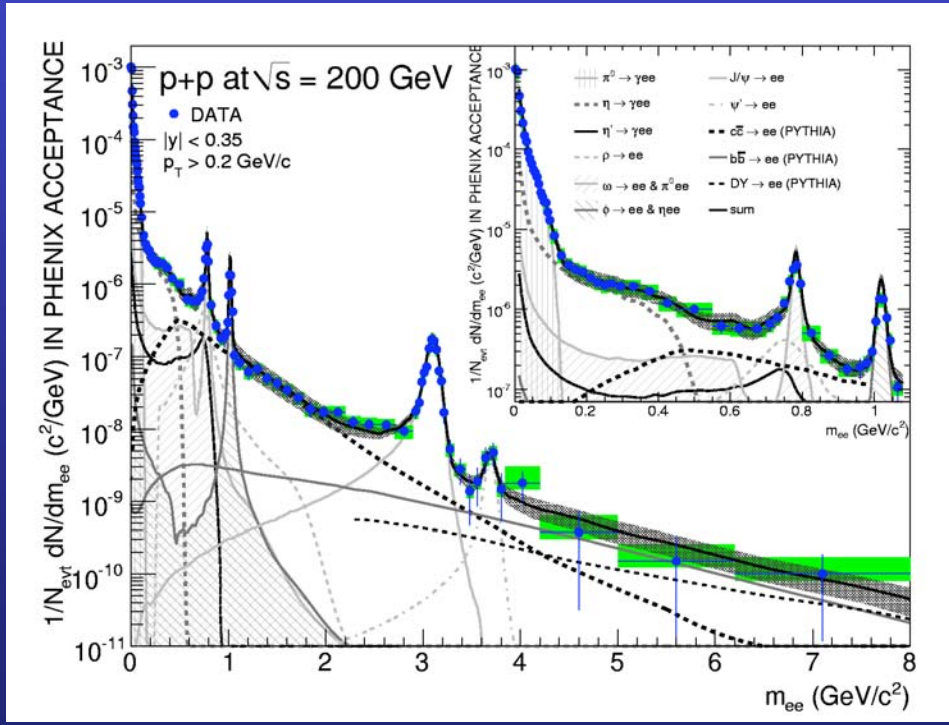
D meson **Inclusive modes**

e^+ anything	[yy]	(6.71 ± 0.29) %
μ^+ anything		(6.5 ± 0.7) %
K^- anything		(53 ± 4) %
$\overline{K}^0$ anything + K^0 anything		(42 ± 5) %

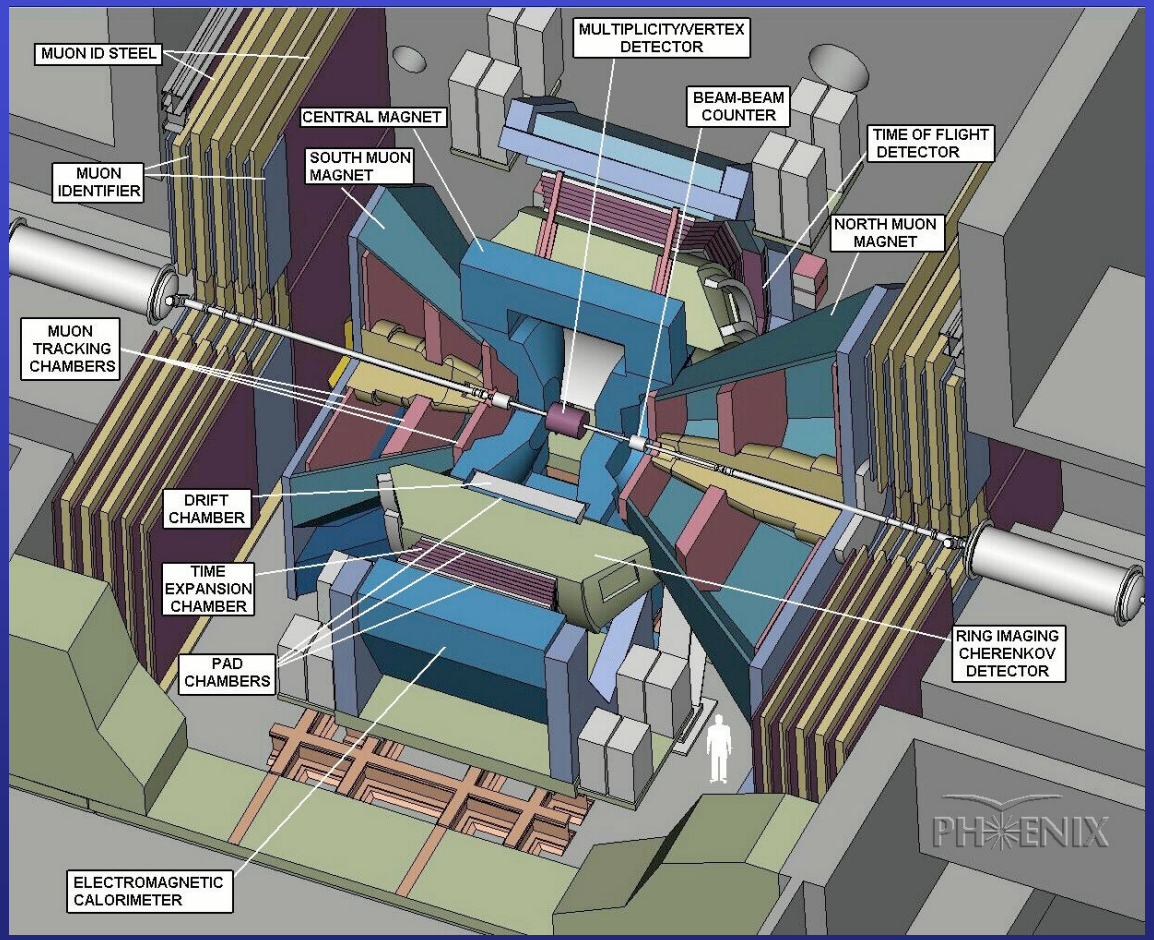
- Also e-hadron correlations, e^+e^-

Quarkonia Measurements

- $J/\psi, \psi', \Upsilon \rightarrow e^+e^-, \mu^+\mu^-$
- $\chi_c \rightarrow J/\psi + \gamma$
- Di-lepton mass peaks must be separated from di-lepton physics backgrounds + combinatorial background

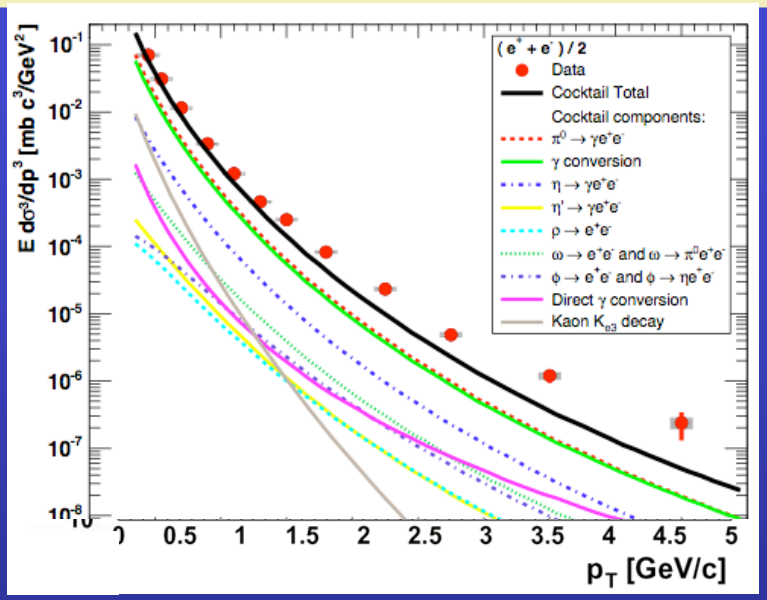


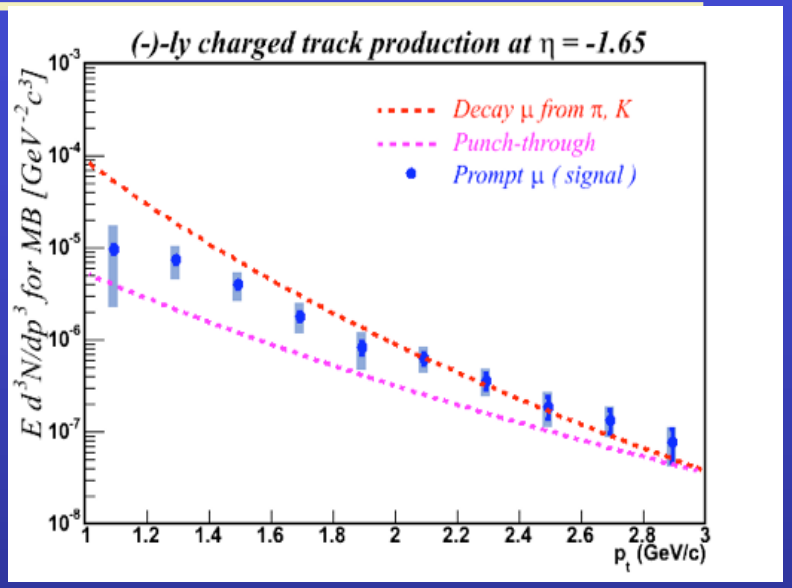
PHENIX Detector



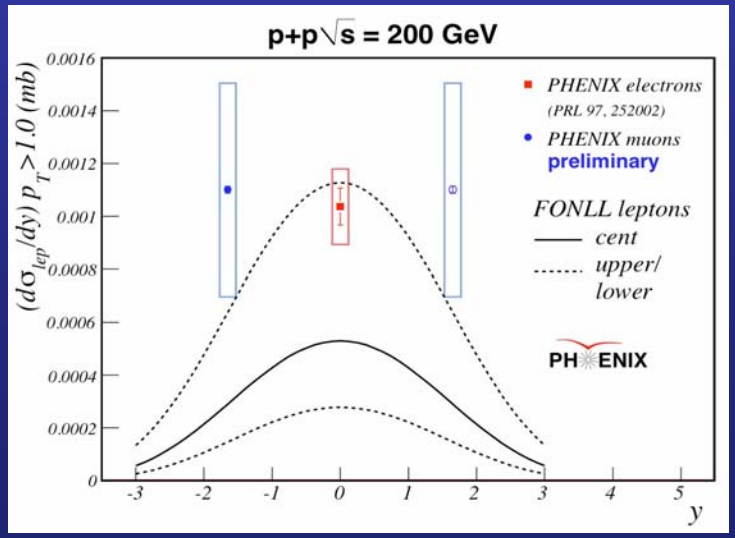
- Global Beam-Beam and Zero-Degree Calorimeter to give vertex, centrality
- Tracking chambers, RICH, EM Calorimeter to give Electron ID
- Tracking + B-field → p
- Time of Flight for PID
- $|y| < 0.35$
- Forward absorbers and Tracking to give Muon ID
- Tracking + B-field → p
- $1.2 < |y| < 2.4$

Results - single leptons in p+p





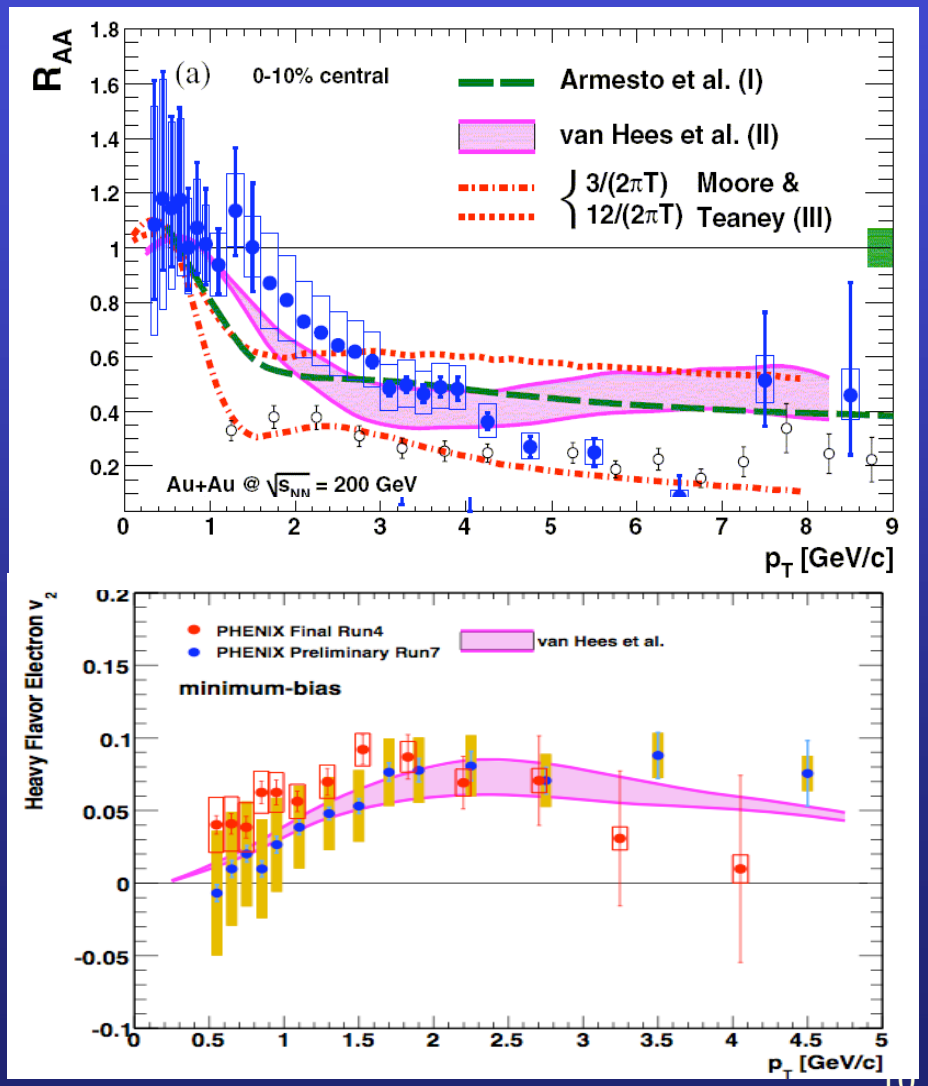
- Deconvolute single e spectrum to extract heavy flavor component
- Same for single muon spectrum
- Cross section vs. p_T, rapidity extracted
- Results consistent with expectations, rapidity dependence poorly constrained
- Upgrades program will significantly improve error bars



Results - single electrons in Au+Au

- p+p p_T spectra extracted
- Au+Au extracted
- $R_{AA} = \frac{dN/dp_T|_{AuAu}}{N_{coll}\, dN/dP_T|_{pp}}$
- Elliptic flow, v_2

- Large suppression relative to binary scaling - Surprise
- Relatively large flow - Surprise
- Uncertainty in c/b contributions complicates interpretation

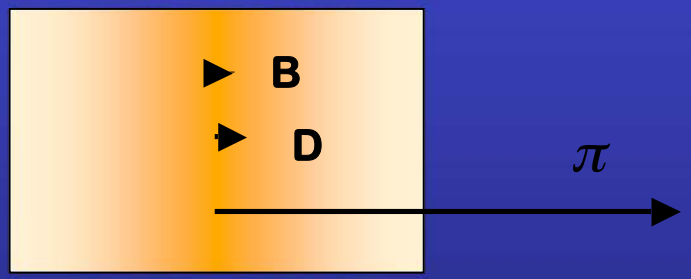


*PRL98, 172301

Models - single electrons in Au+Au

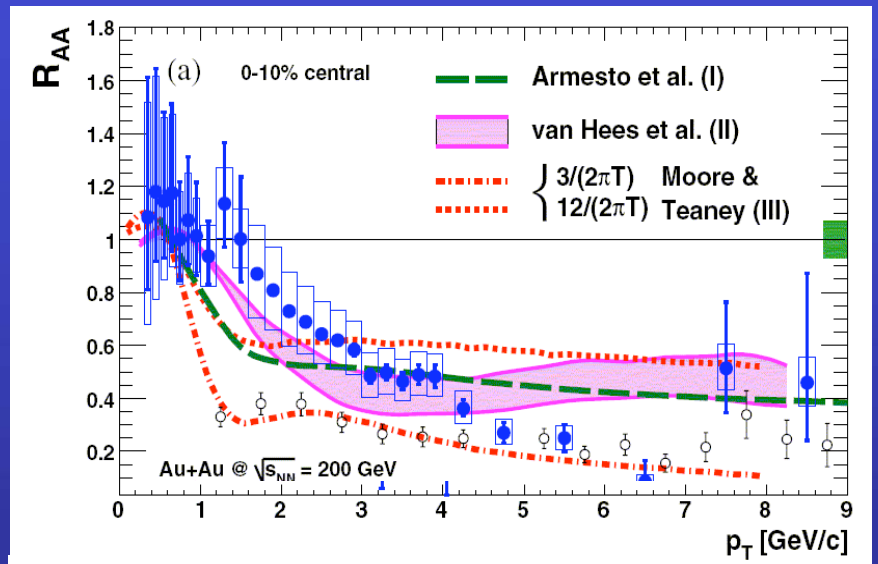
- Is there significant collisional energy loss?
- Does short formation time allow for collisional dissociation?

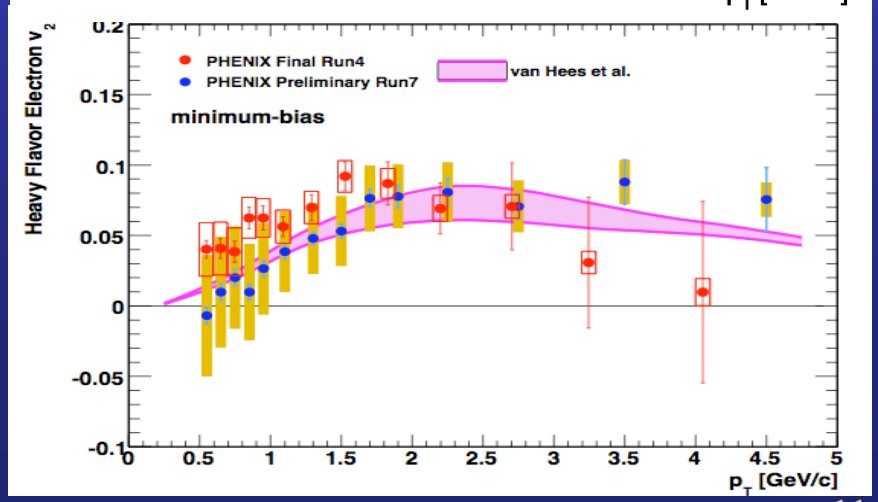
QGP extent



$\tau_{form}\,(p_T = 10\ GeV)$	π	D	B
	25 fm	1.6 fm	0.4 fm

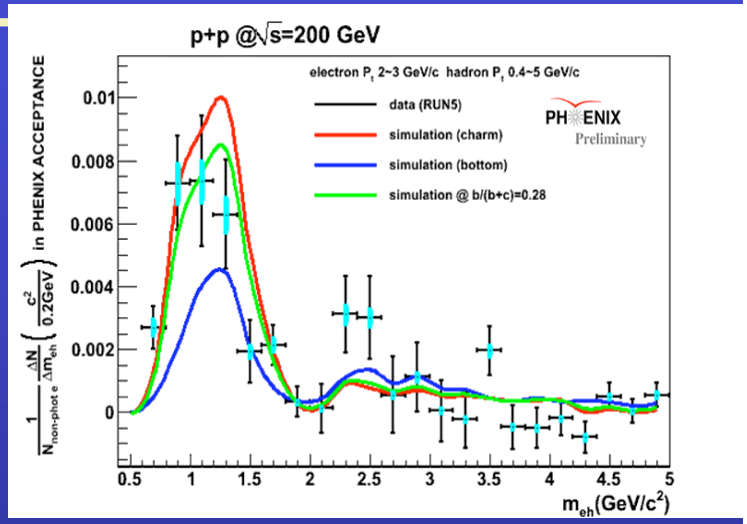
- Can a consistent energy loss and flow model describe all the data?
- Want to separate D/B and get higher precision data

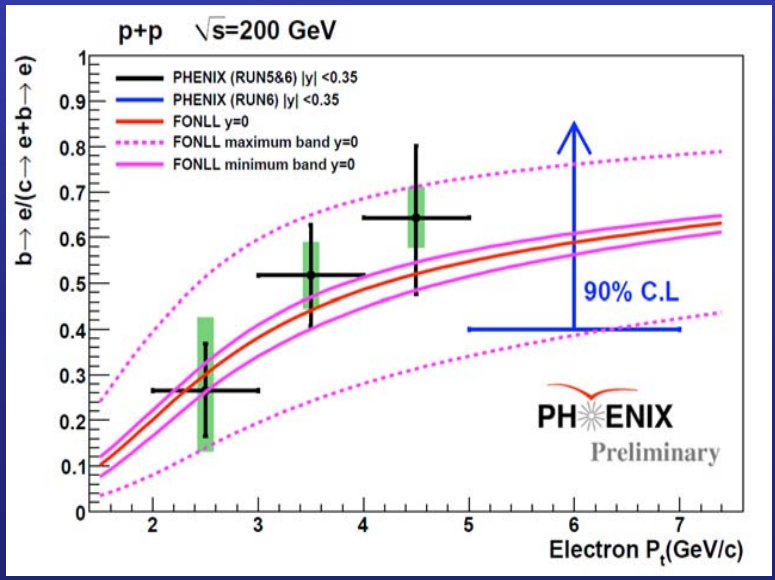


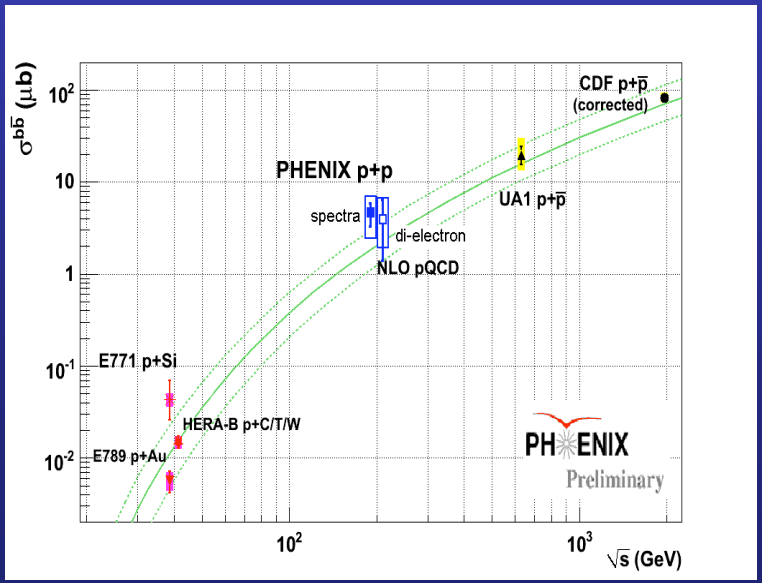


Results - charm:beauty in single electrons

- Use correlated e-K to extract charm:beauty ratio versus p_T
- Invariant mass distribution different for charm/beauty
- Fit two components to real data and extract c:b
- Beauty becomes dominant ~ >3.5 GeV

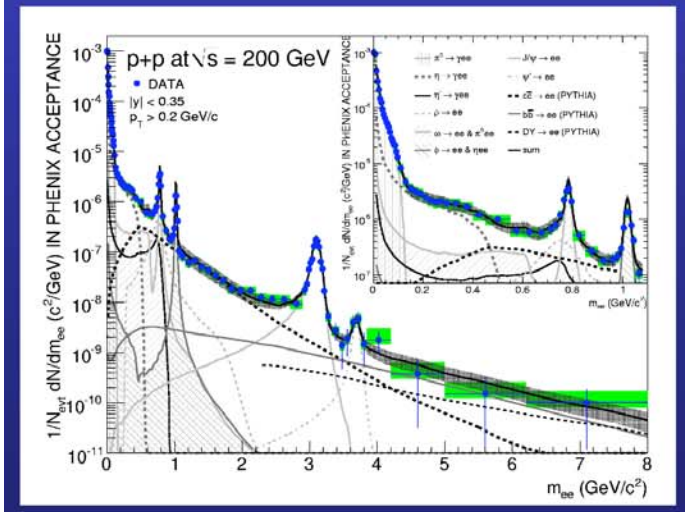


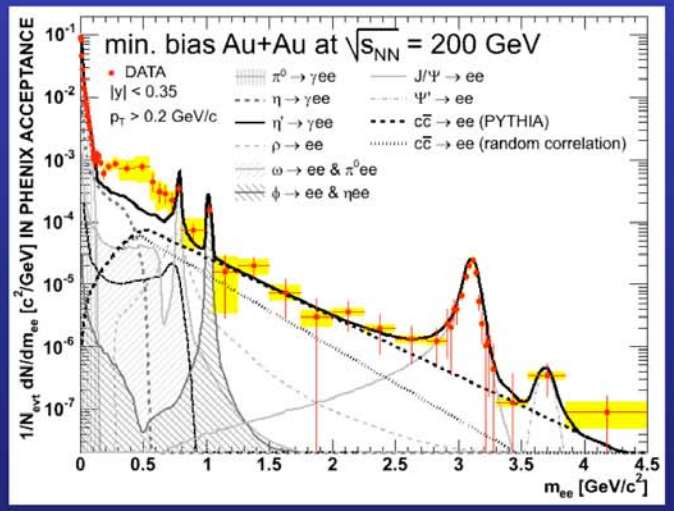


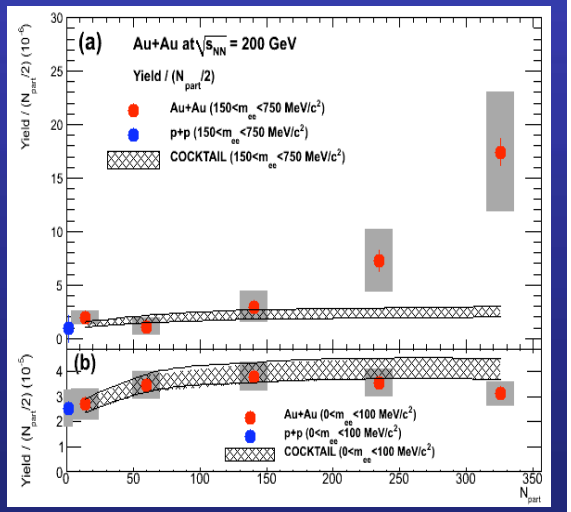


Results - Open Heavy Flavor from Di-Electrons

- Dielectron invariant mass measured in p+p and Au+Au
- Compared to cocktail of all known sources
- p+p data agree very well with cocktail
- Au+Au data show centrality-dependent enhancement in 150 MeV < m < 750 MeV region
- Thermal photons contributing to excess?



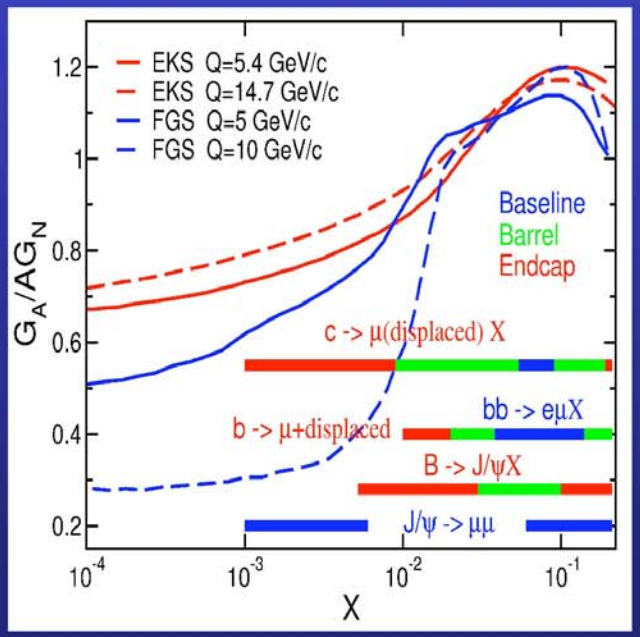


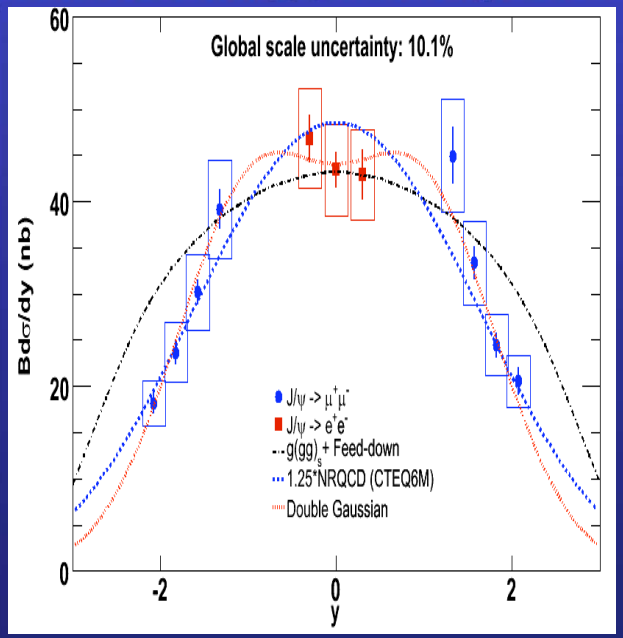


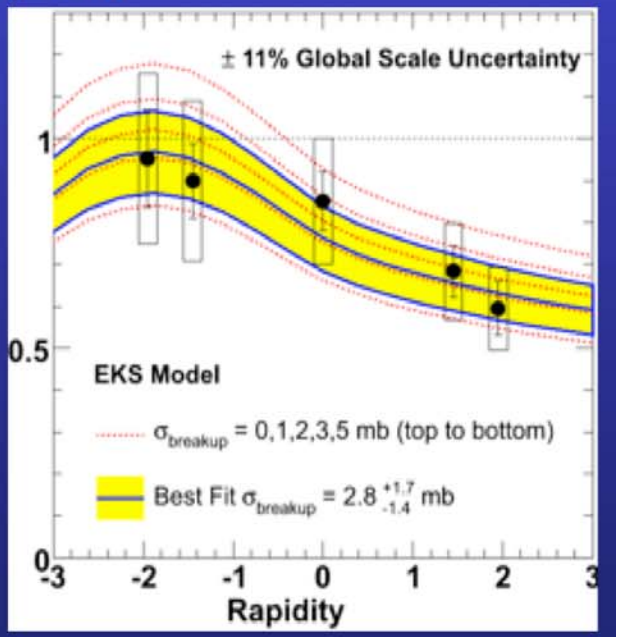
*arXiv:0802.0050, arXiv:0706.3034

Results - J/ψ R_{AA} in p+p, d+Au Collisions

- p+p and d+Au J/ψ measurements give baseline measurement for A+A plus measurement of cold nuclear matter modifications to production
- Rapidity dependence sensitive to gluon shadowing
- Some forward/backward rapidity modification found w.r.t p+p, consistent with some shadowing plus J/ψ absorption



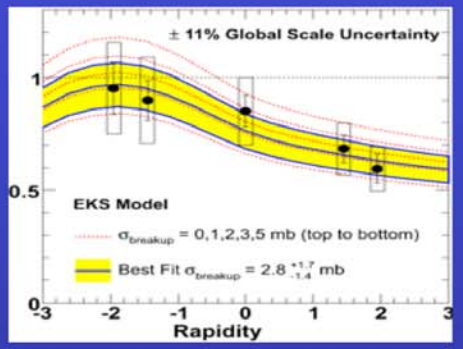




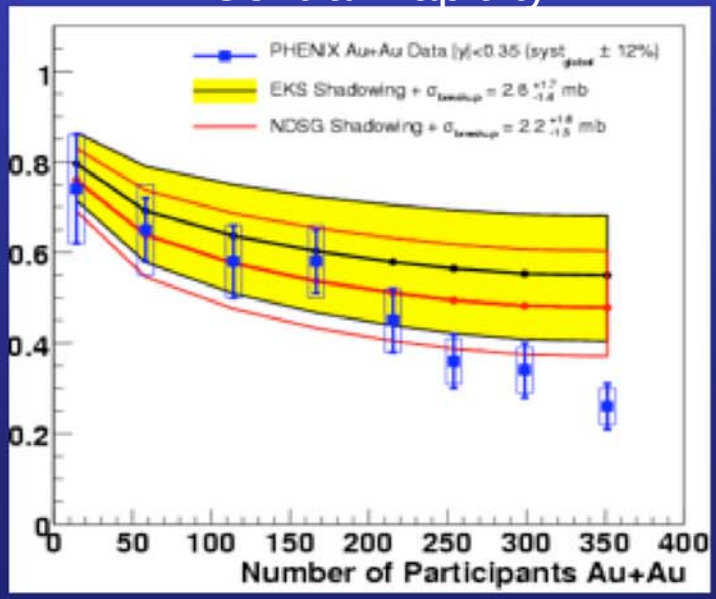
*pp: PRL98,232002, dAu: PRC77, 024912

Results - J/ψ R_{AA} in Au+Au Collisions

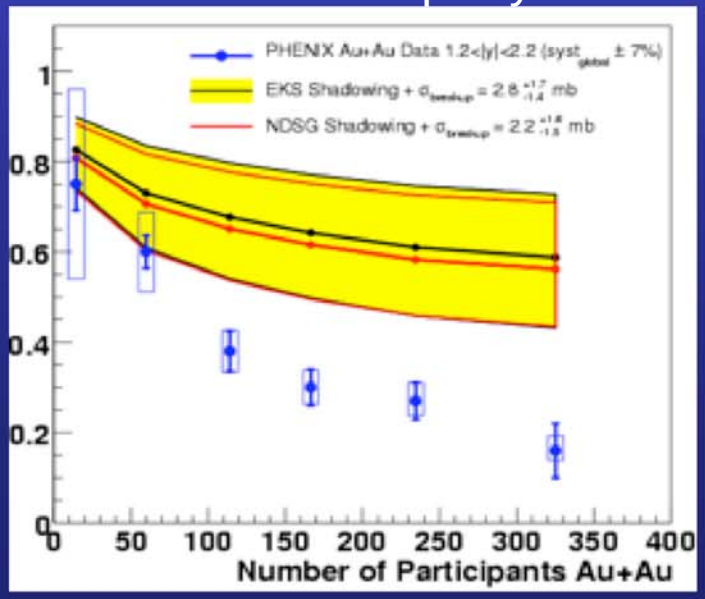
- J/ψ d+Au extrapolated to Au+Au and compared to measurements
- Additional suppression found, especially at forward rapidity
- Would different CNM extrapolation give different rapidity dependence? Is recombination at play?



Central Rapidity



Forward Rapidity

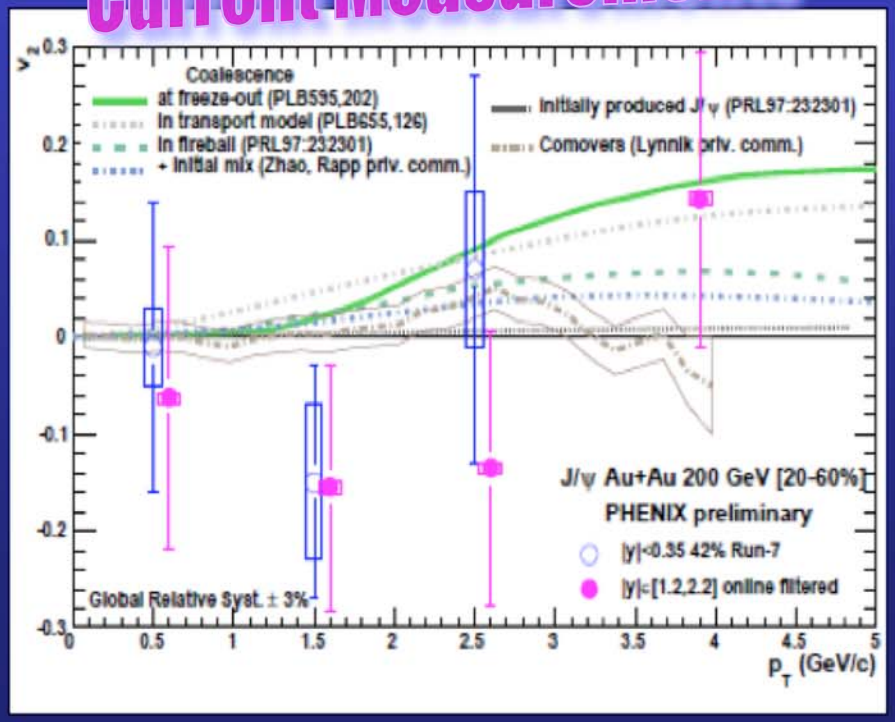


*PRL98, 232301

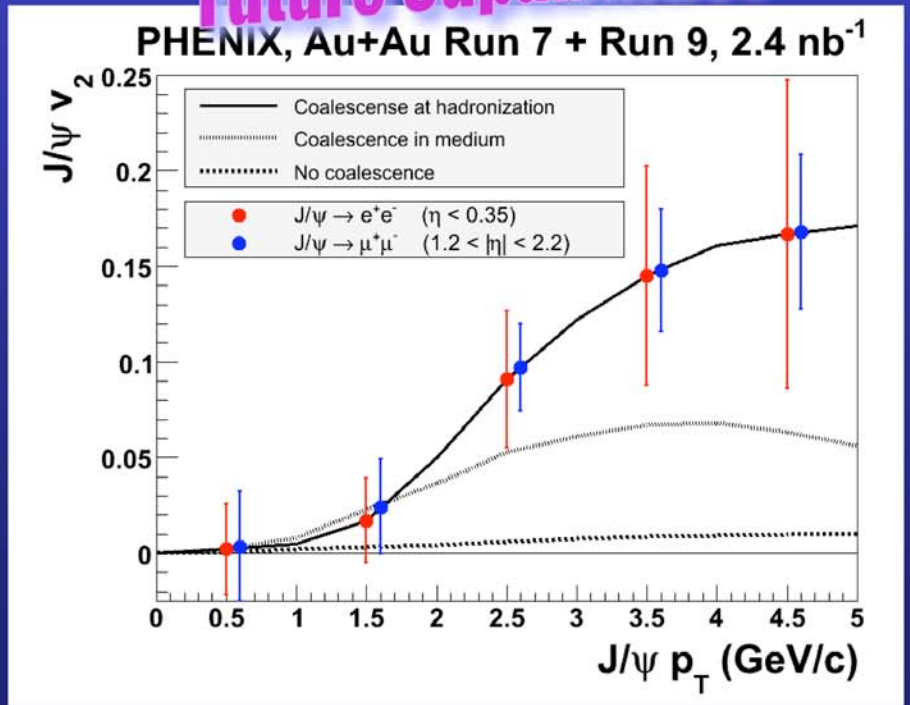
Results - J/ψ Flow Measurements

- If open heavy flavor shows strong flow, and coalescence contributes significantly to J/ψ formation, should see J/ψ flow
- Current data cannot distinguish models, but higher statistics could provide valuable information

Current Measurements

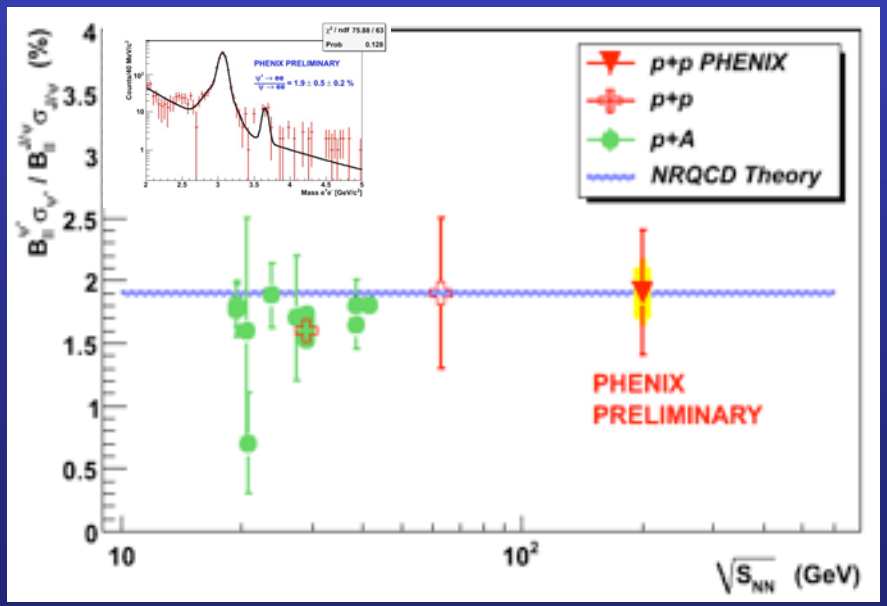


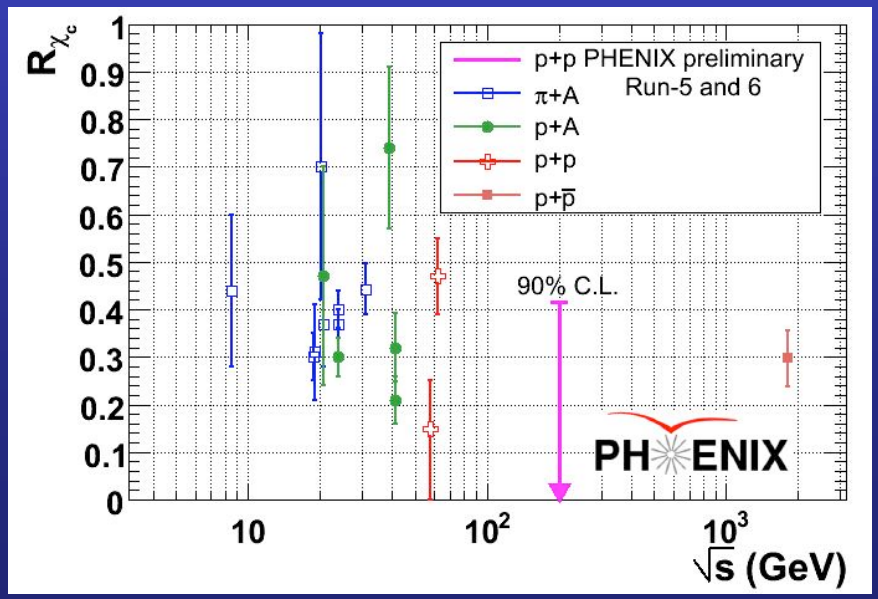
Future Capabilities



Results - Other Quarkonia Measurements

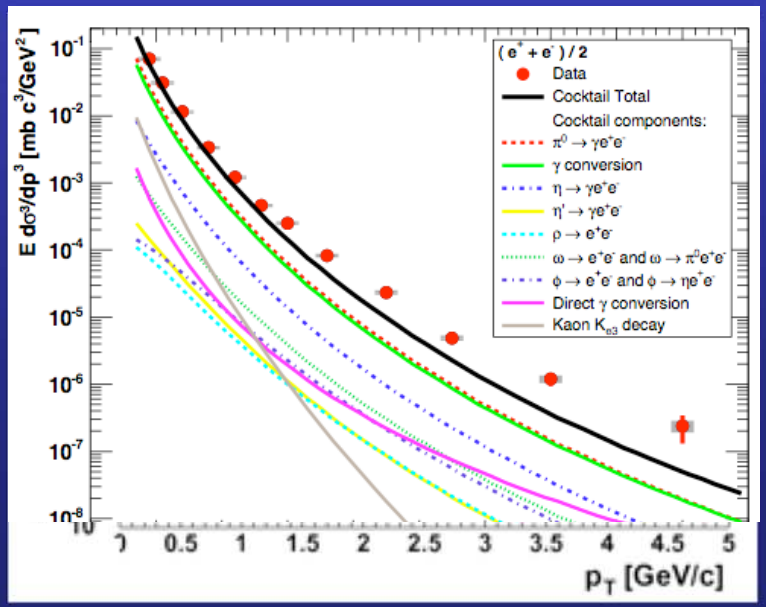
- Additional quarkonia measurements could constraint screening
- J/ψ : ψ' ratio extracted at central rapidity in p+p
- Same extracted for χ_c using $\chi_c \rightarrow J/\psi\ \gamma \rightarrow e^+e^-\gamma$
- Production ratios consistent with previous measurement extrapolations
- Not enough statistics to perform detailed ψ', χ_c analyses
- Upgrades program will help

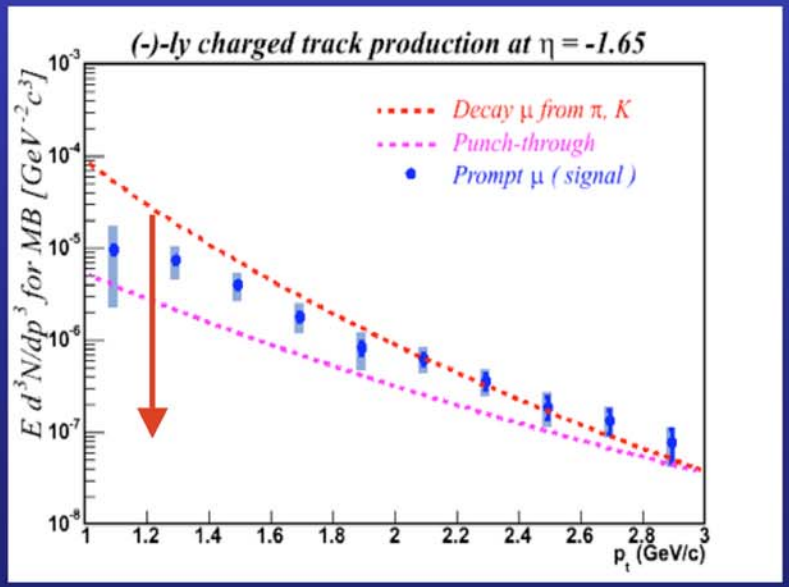




How to Improve Heavy Flavor Measurements

- Improved background rejection in semi-leptonic decay measurements would allow systematic errors to be reduced
- Separation of charm/beauty allows quark mass dependence to be mapped out
- Add additional quarkonia measurements with improved mass resolutions, background rejection, added acceptance





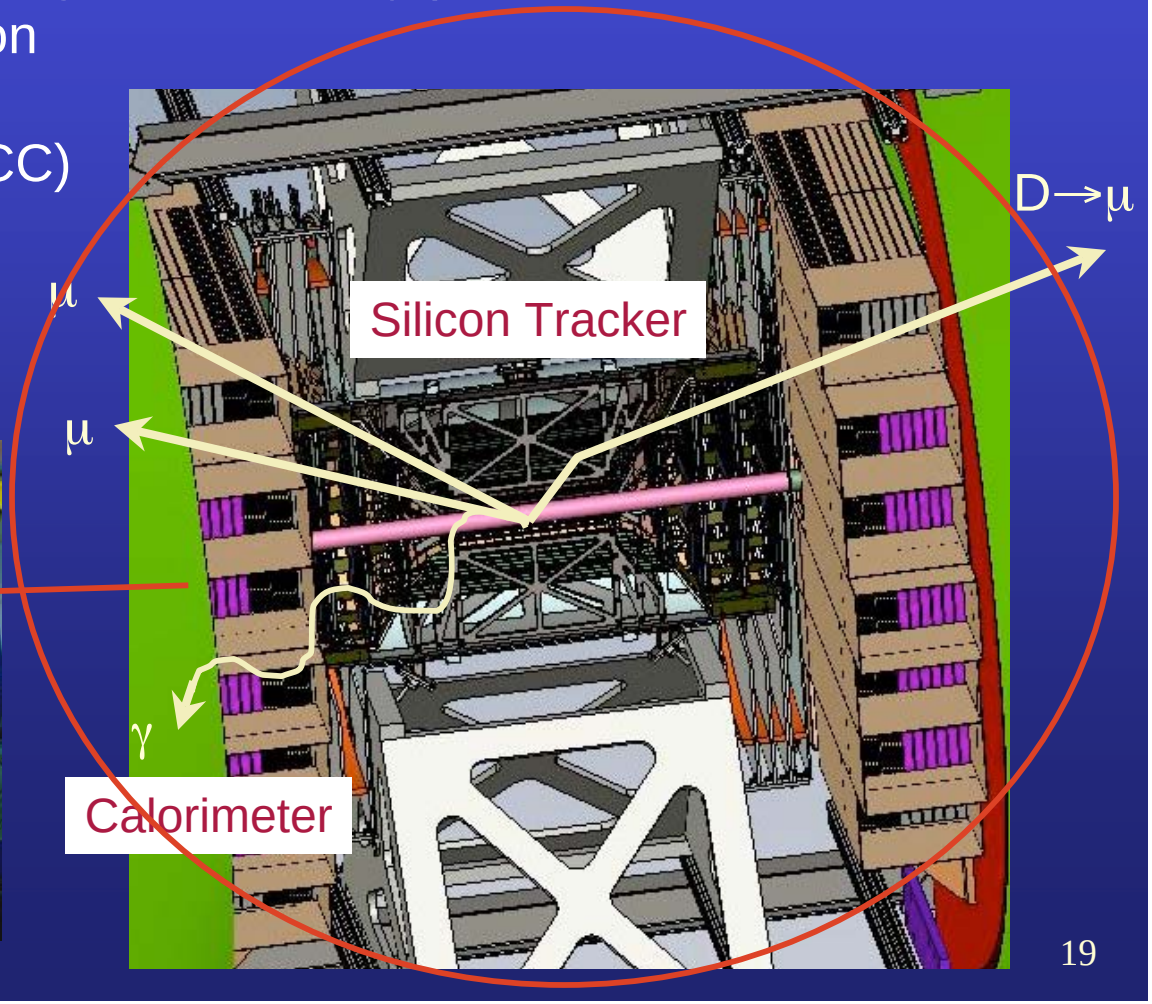
PHENIX Upgrade Capabilities

Silicon Vertex Trackers (VTX and FVTX)

- Displaced vertex tagging of D, B decay products
- Direct D reconstruction
- Ψ', upsilons

Nosecone Calorimeter (NCC)

- χ_c



PHENIX Upgrade Capabilities

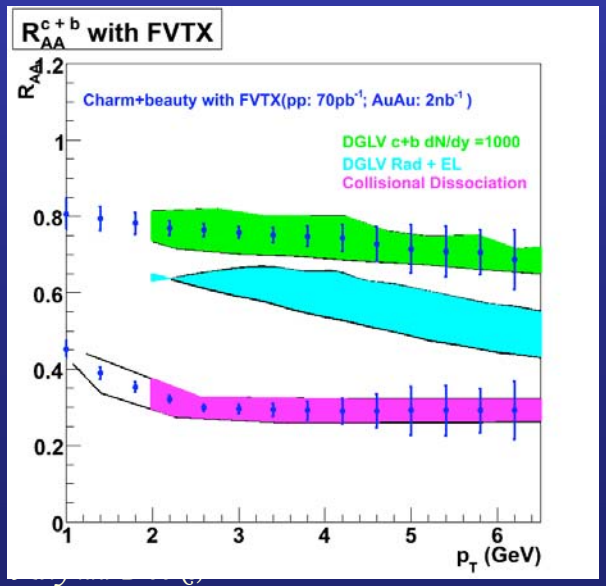
Silicon Vertex Trackers (FVTX and VTX)

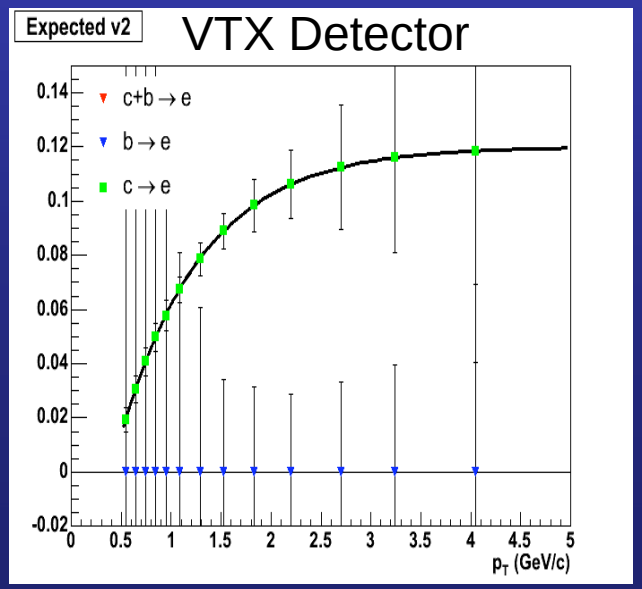
- much improved heavy flavor → e, μ measurements
- Direct D reconstruction from hadronic decay
- Ψ', upsilons

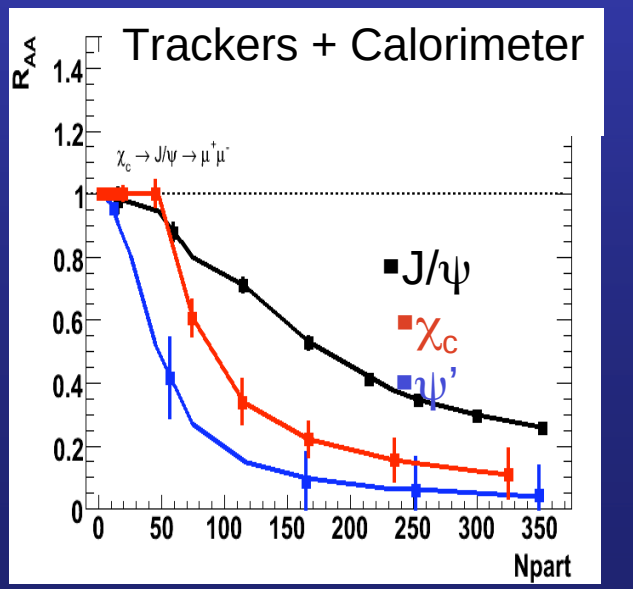
Nosecone Calorimeter (NCC)

- χ_c

- Energy loss mechanisms in QGP understood
- Recombination contributions to quarkonia production better constrained
- Screening of quarkonia mapped out







Summary

Current:

- Large heavy flavor suppression in Heavy Ion Collisions - Why?
- Significant open heavy flavor elliptic flow, J/ψ uncertain
- Large J/ψ suppression, but surprising rapidity dependence
- Cold Nuclear Matter modification to production seen, but components poorly constrained

Future:

- New d+Au results from RHIC Run 8 - CNM constrained
- Significantly reduced systematic errors on heavy flavor → separation of suppression mechanisms

Upgrades

- Higher statistics, improved J/ψ → does J/ψ flow?, is recombination playing significant role in production?
- New quarkonia measurements → screening pattern revealed